Additive Manufacturing in the Nuclear Industry

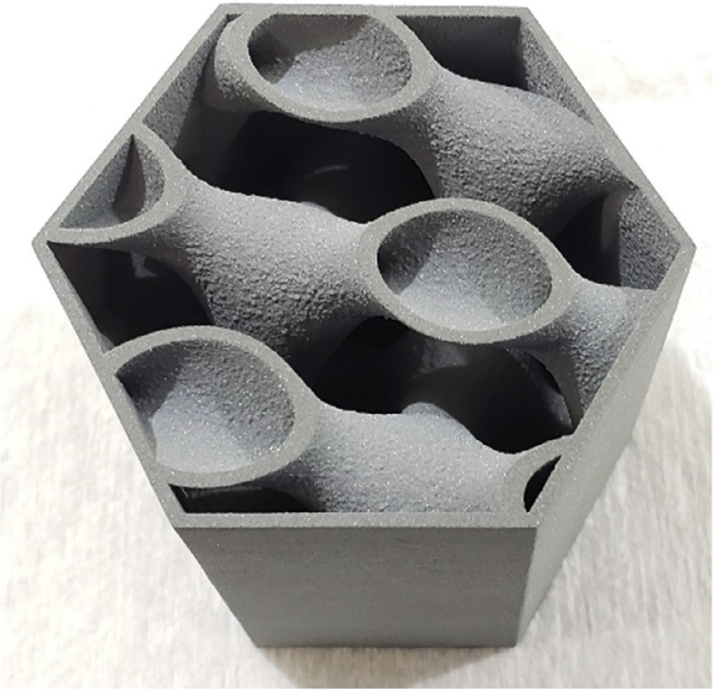
Benjamin R. Betzler, Ph.D.
Director, Transformational Challenge Reactor
Senior R&D Staff

27 July 2021

ORNL is managed by UT-Battelle, LLC for the US Department of Energy

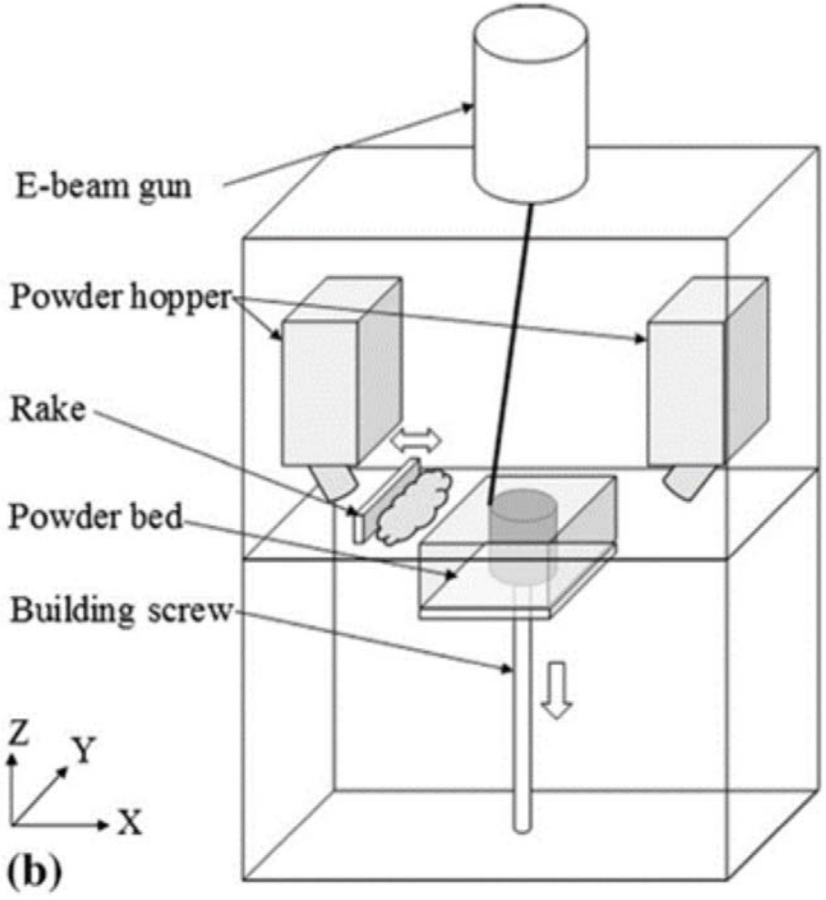
Overview of additive manufacturing technologies

- Creates a part layer by layer based on the specifications provided in a three-dimensional digital model
  - Reduced product development times
  - Integrated design and manufacturing efforts
  - Enable complex geometries once unattainable using traditional fabrication approaches
  - Ideal for high value and low-volume production
- Applicability of methods depend on
  - Material type and density
  - Overall part dimension
  - Minimum feature size
  - Postprocessing requirements

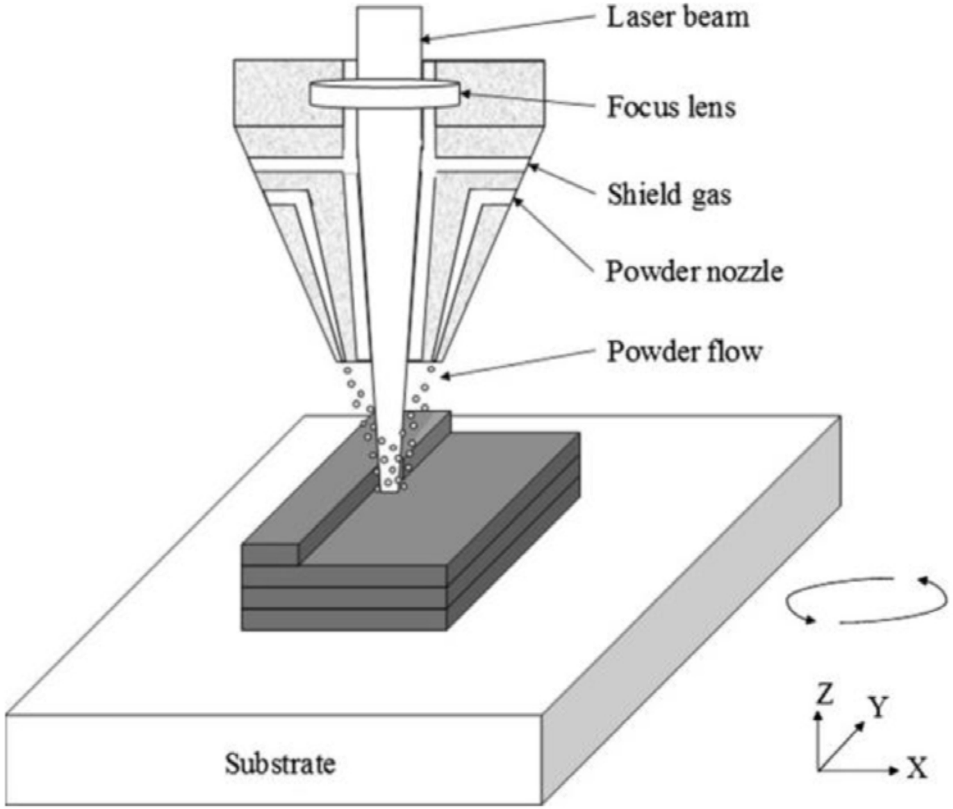


Additive manufacturing technologies

Powder bed fusion

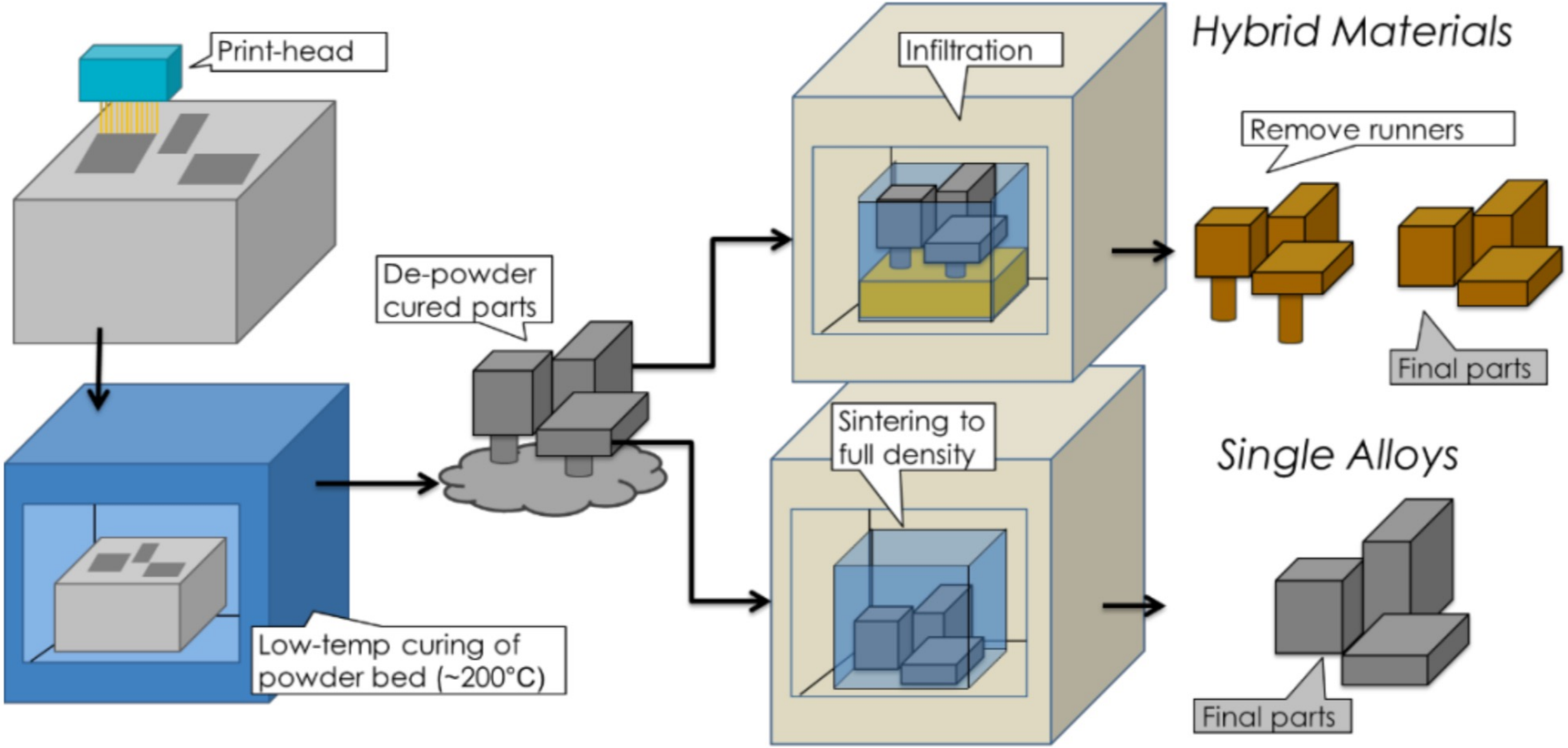


Directed energy deposition

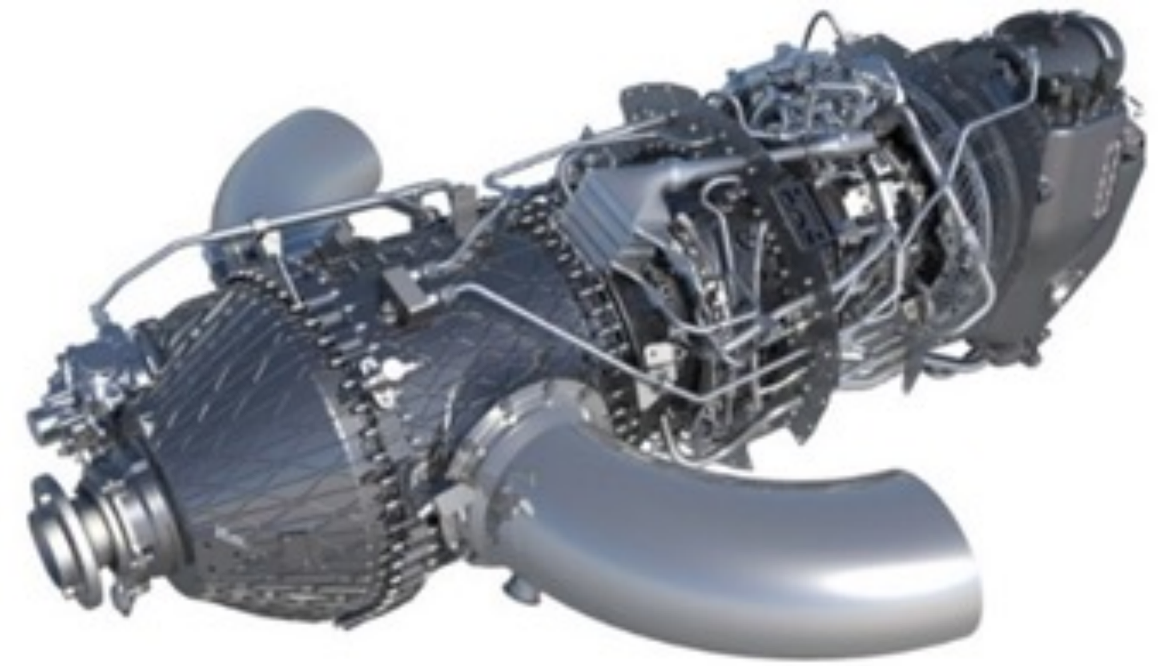


Additive manufacturing technologies

Binder jetting



Why are we applying these technologies in nuclear



GE additively manufactured jet engine (courtesy of General Electric)

Other industries have benefited from additive manufacturing.

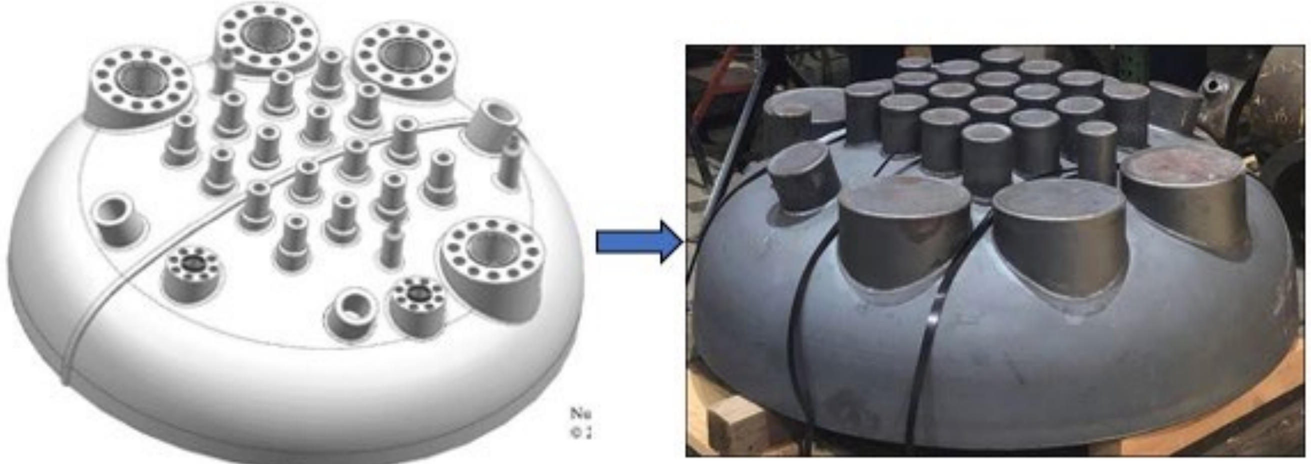
July 2016, successful flight of V-22 with flight-critical part made with additive manufacturing.

General Electric Aviation testing new additively manufactured engines

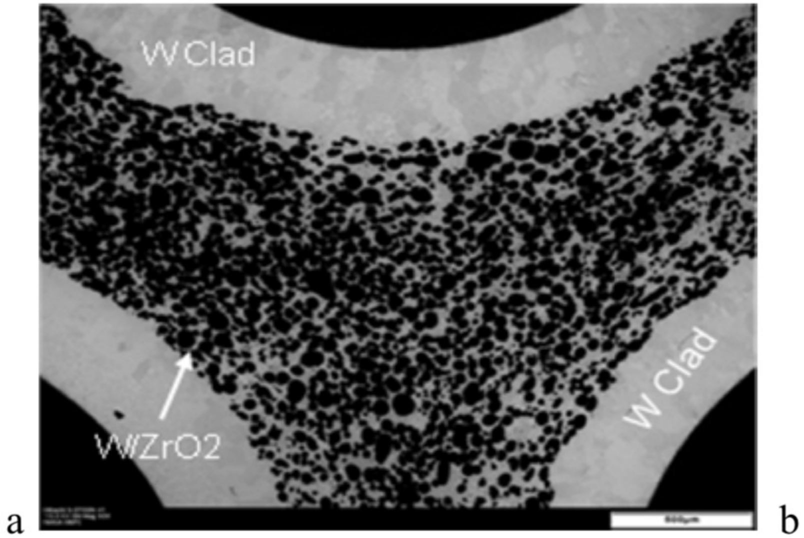
- Reduced part count from 855 separate parts to only 12 parts
- Reduced new design from 10 years from start to prototype to only 2 years

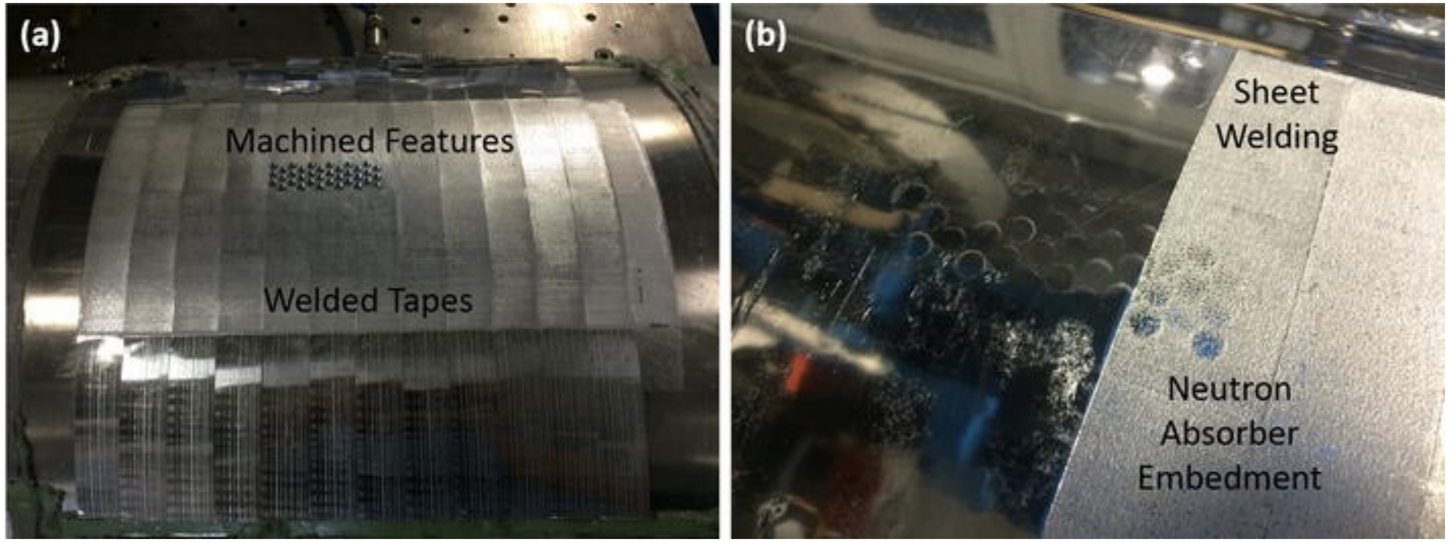
In a similar manner, a program focused on exploring the potential of advanced manufacturing in the nuclear power industry may completely change the way the nuclear industry designs and manufactures.

Nuclear applications of advanced manufacturing



Small Modular Reactor Pressure Vessel Head,
Gandy and Stover, 2018



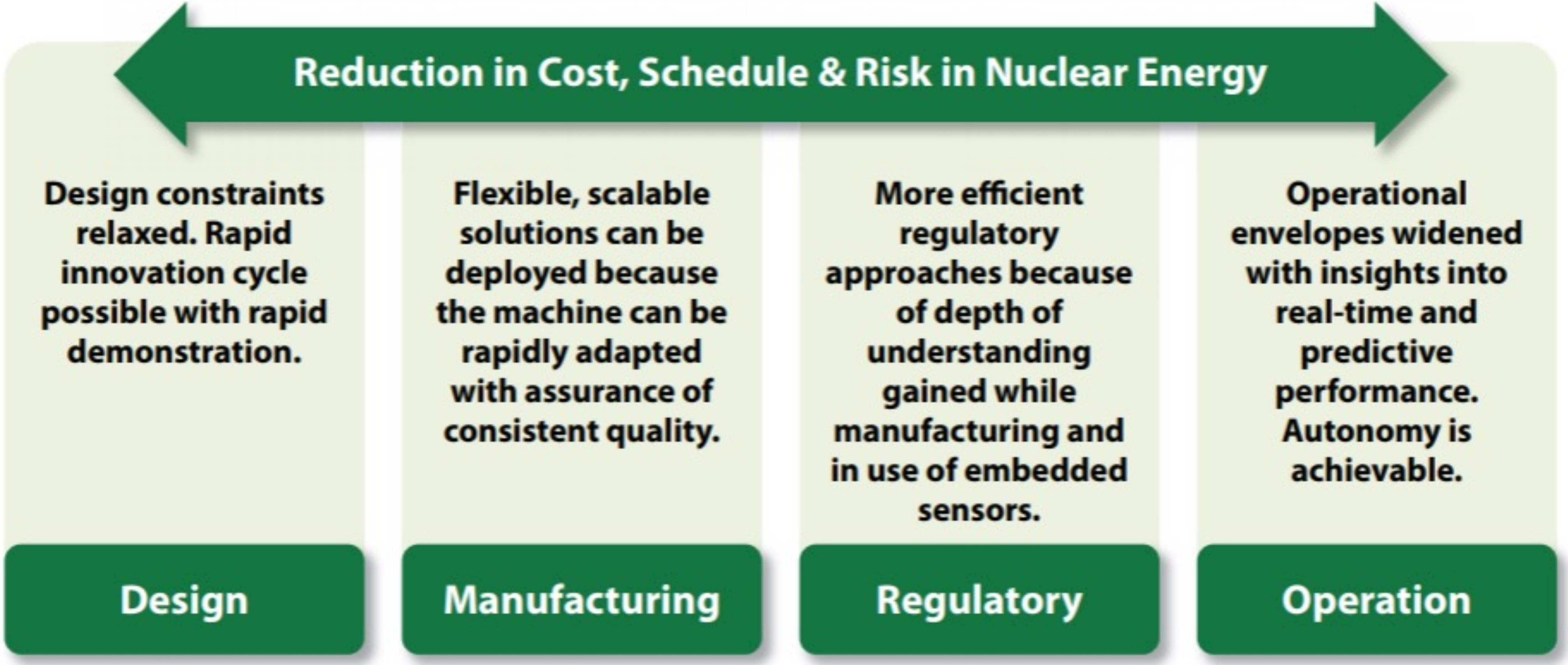


High Flux Isotope Reactor Control Elements,
Hehr et al., 2017

Ceramic Metallic Fuel Element,
Houts et al., 2013

Transformational Challenge Reactor (TCR) Program

Laying the Foundation for Using Additive Manufacturing for Nuclear Energy Systems



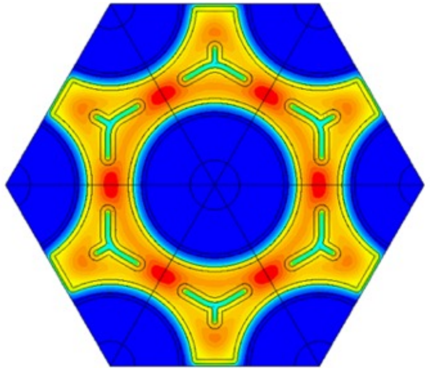
TCR is applying additive manufacturing (AM) and artificial intelligence (AI) to deliver a new approach for nuclear

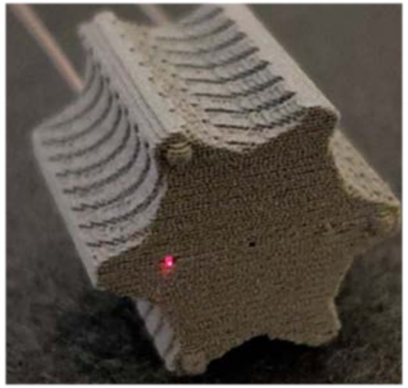
Using AI to navigate an unconstrained design space and realize superior performance

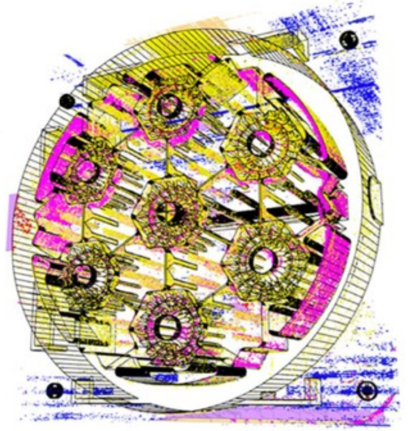
Leveraging AM to arrive at high-performance materials in complex geometries

Exploiting AM to incorporate integrated and distributed sensing in critical locations

Using AI to assess critical component quality through in situ manufacturing signatures



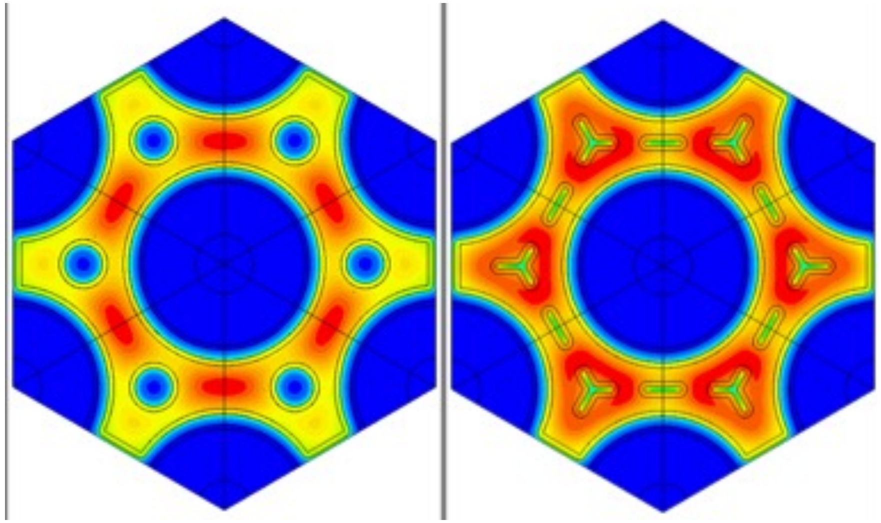




AI-informed Design	Advanced Materials	Integrated Sensing and Control	Digital Platform

tcr.ornl.gov

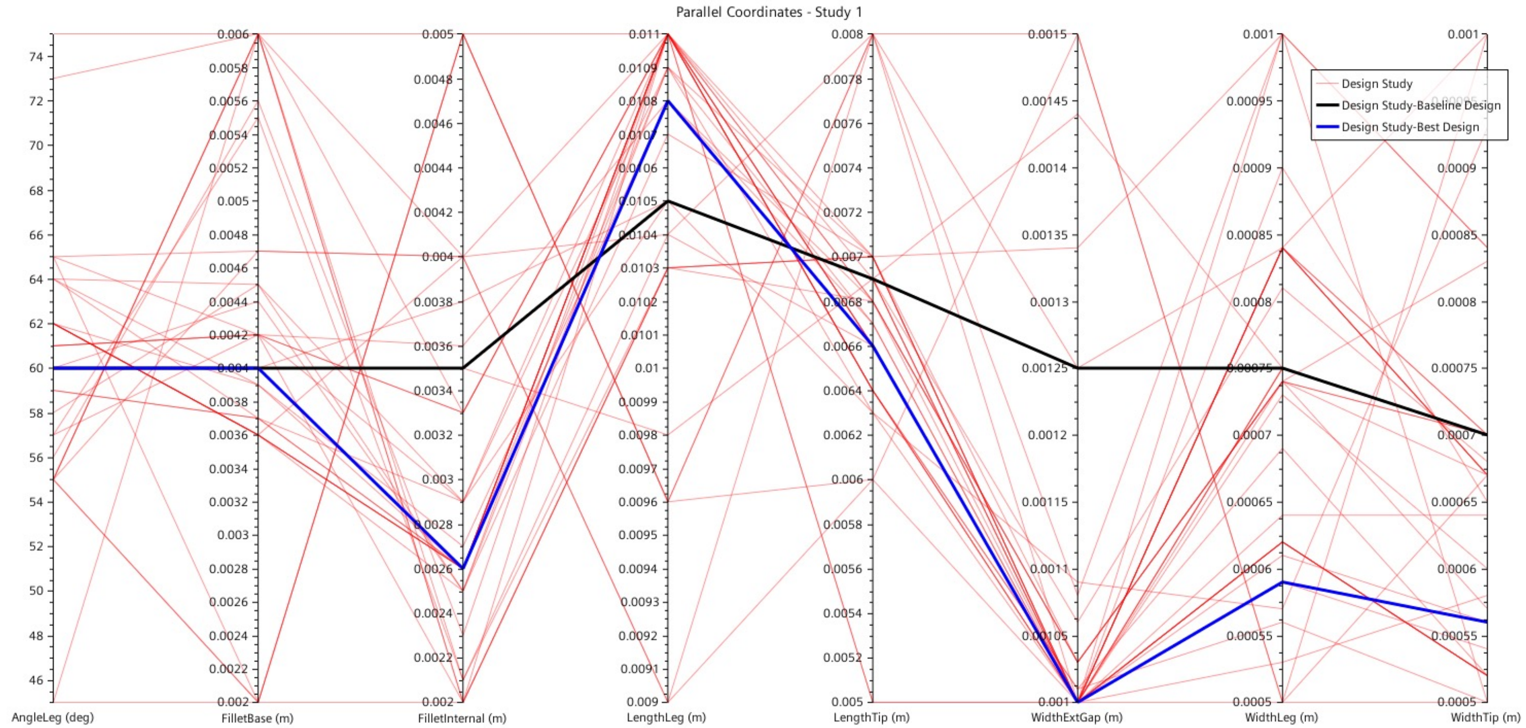
Navigating the unconstrained deigns space offered by additive manufacturing present challenges and opportunities



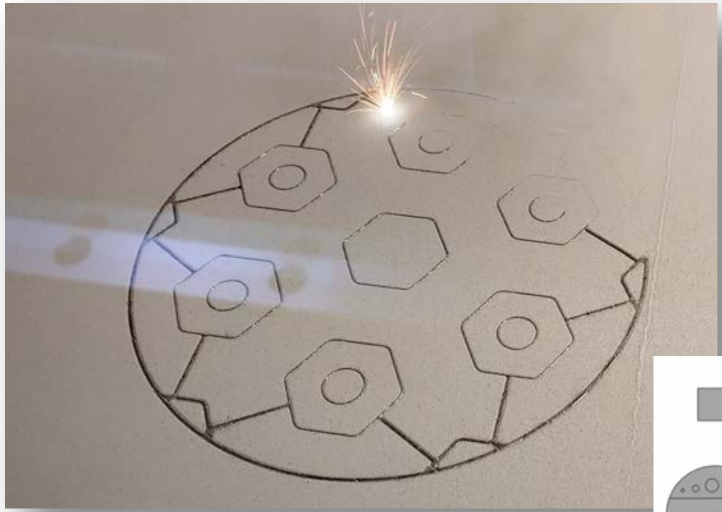
Tmax = 687 C, ΔT = 119 C
Core ΔP = 0.56 psi

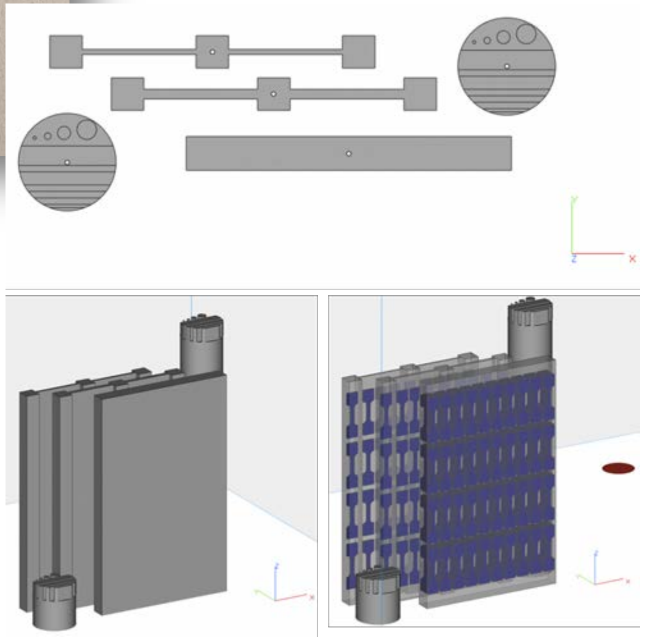
Tmax = 622 C, ΔT = 78 C
Core ΔP = 1 psi

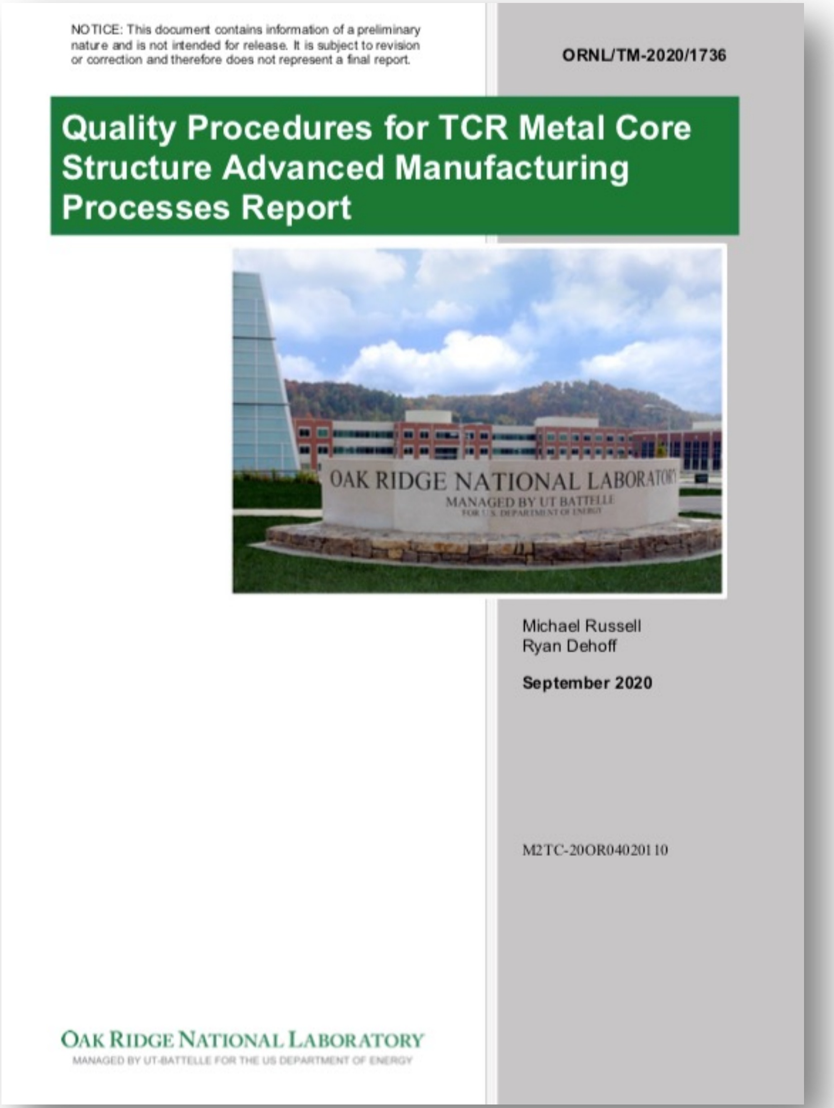
parameter space search to find optimized cooling channel design



Metal additive manufacturing with a focus on powder bed methodologies was codified for production of nuclear components







NOTICE: This document contains information of a preliminary nature and is not intended for release. It is subject to revision or correction and therefore does not represent a final report.

ORNL/TM-2020/1736

Quality Procedures for TCR Metal Core Structure Advanced Manufacturing Processes Report

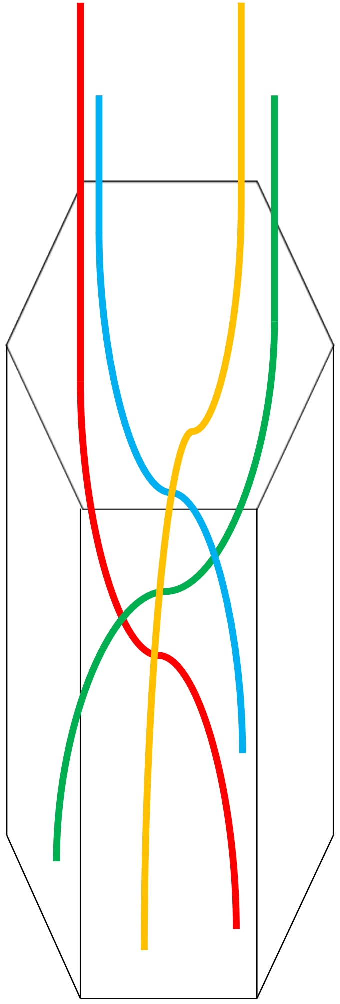
Michael Russell
Ryan Dehoff

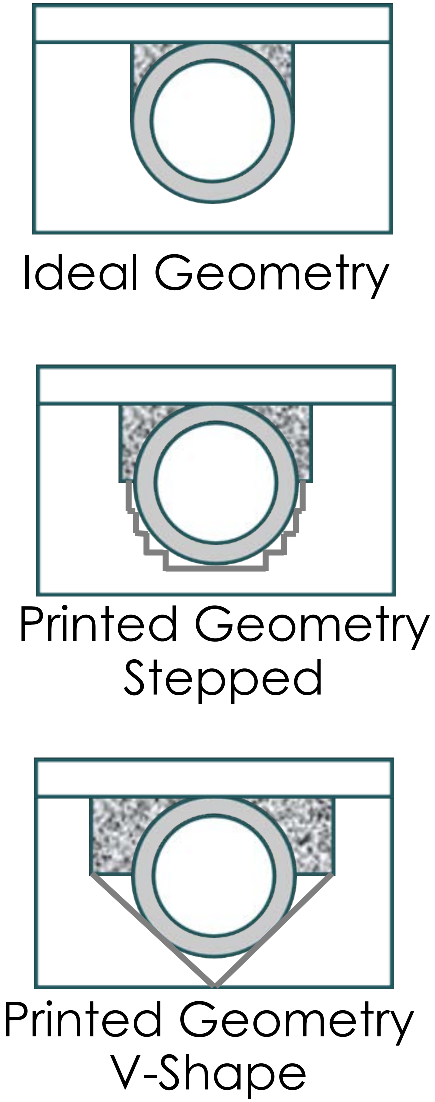
September 2020

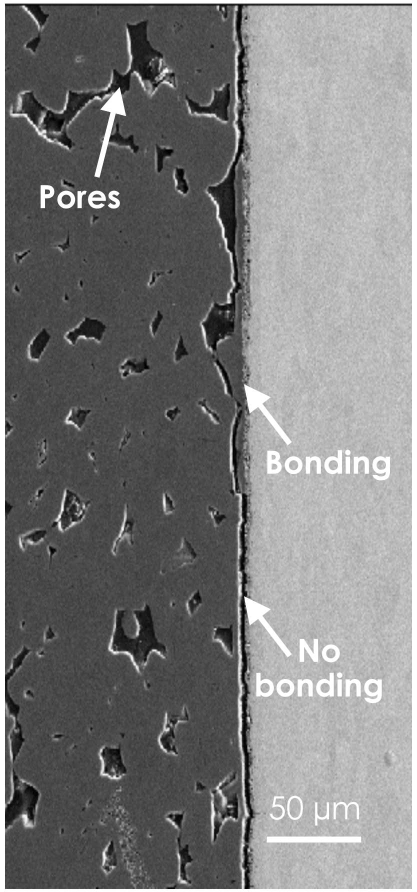
M2TC-20OR0402011 0

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

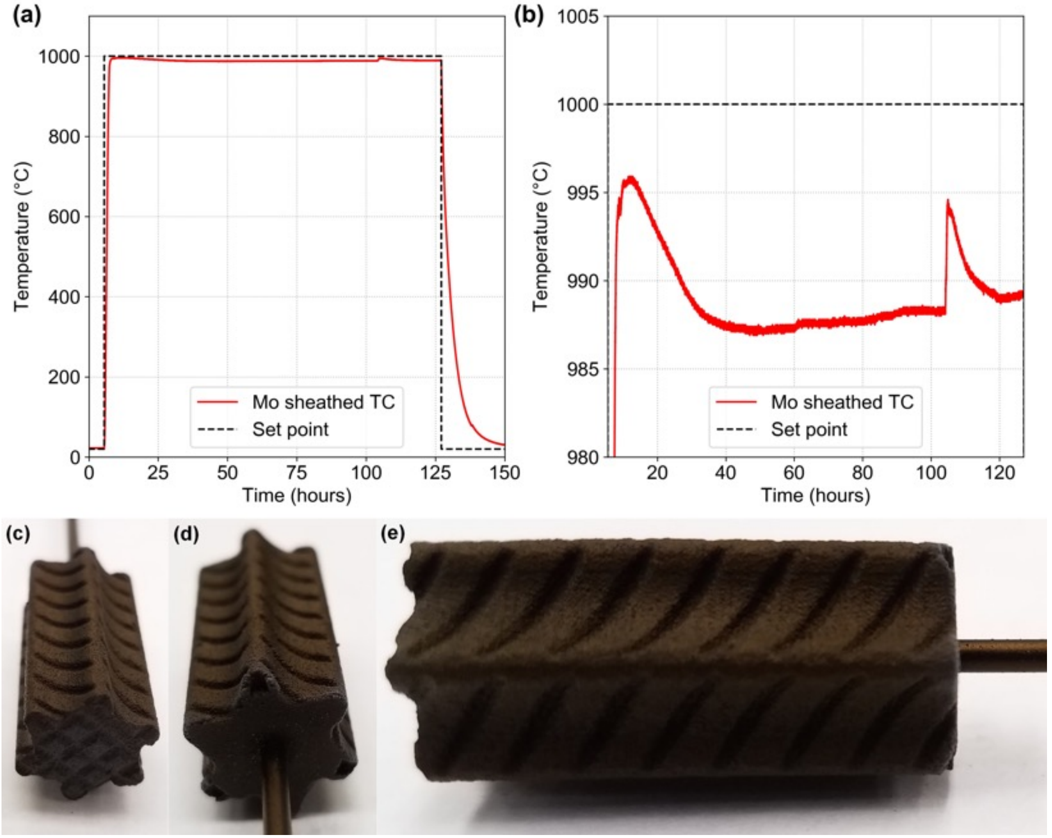
Embedding sensors in critical locations within components informs operations and modeling





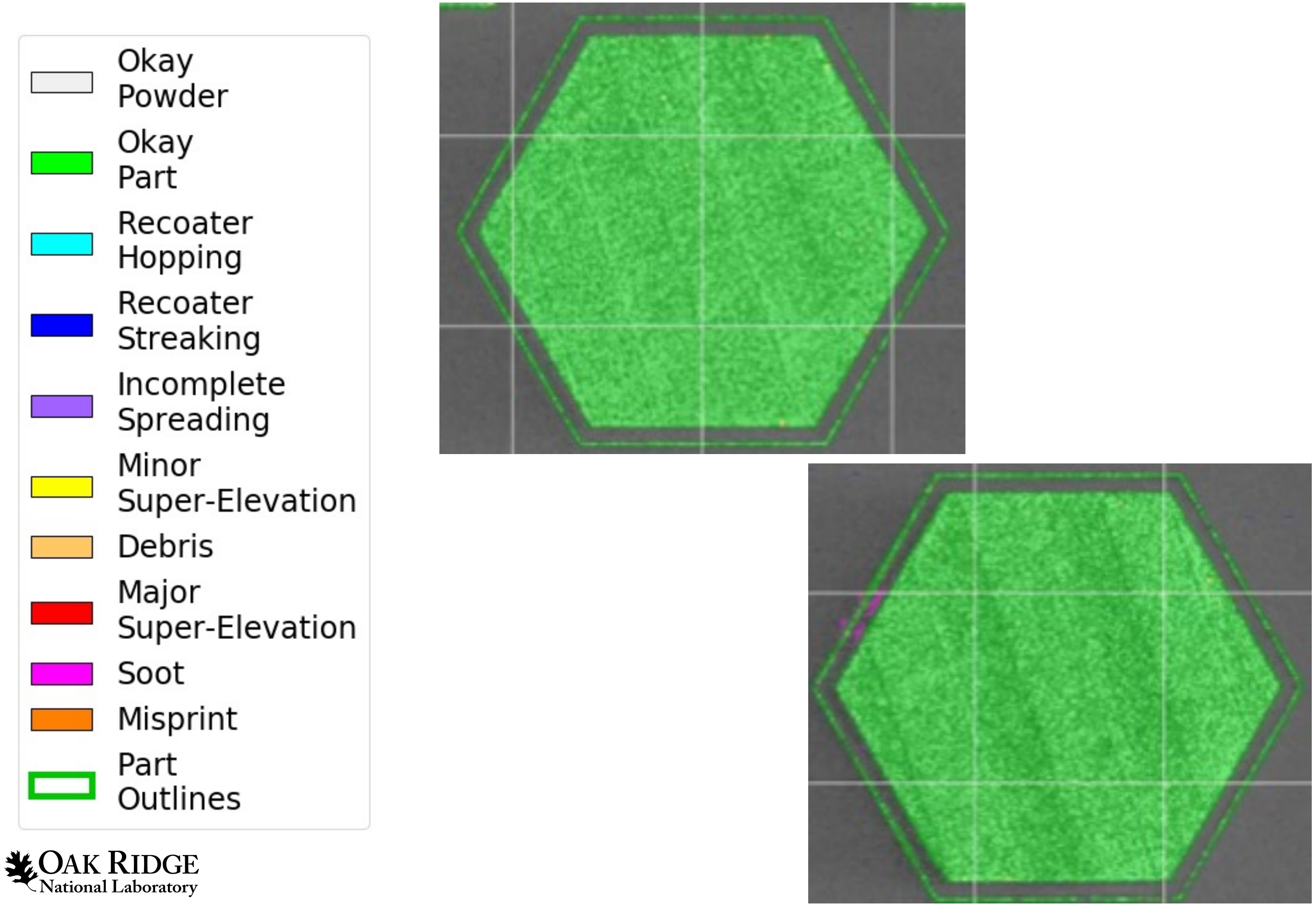


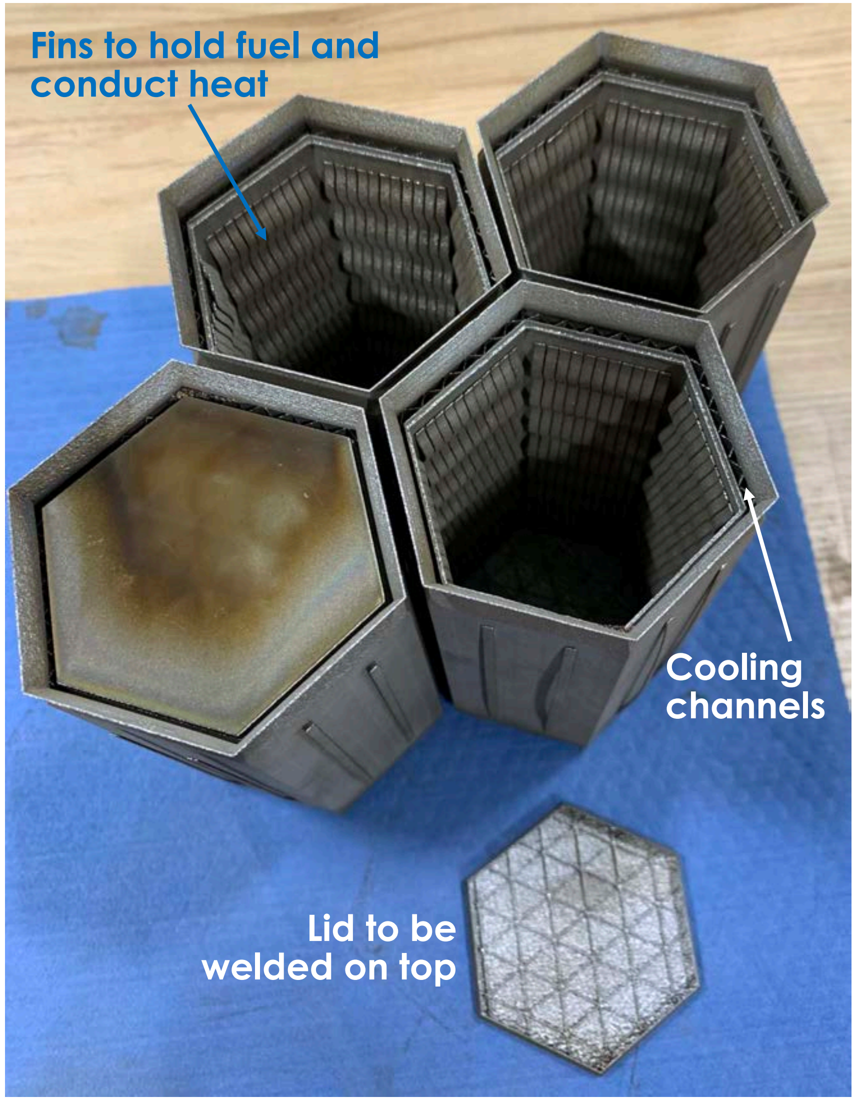
Embedded sensor sheath in additively manufactured silicon carbide



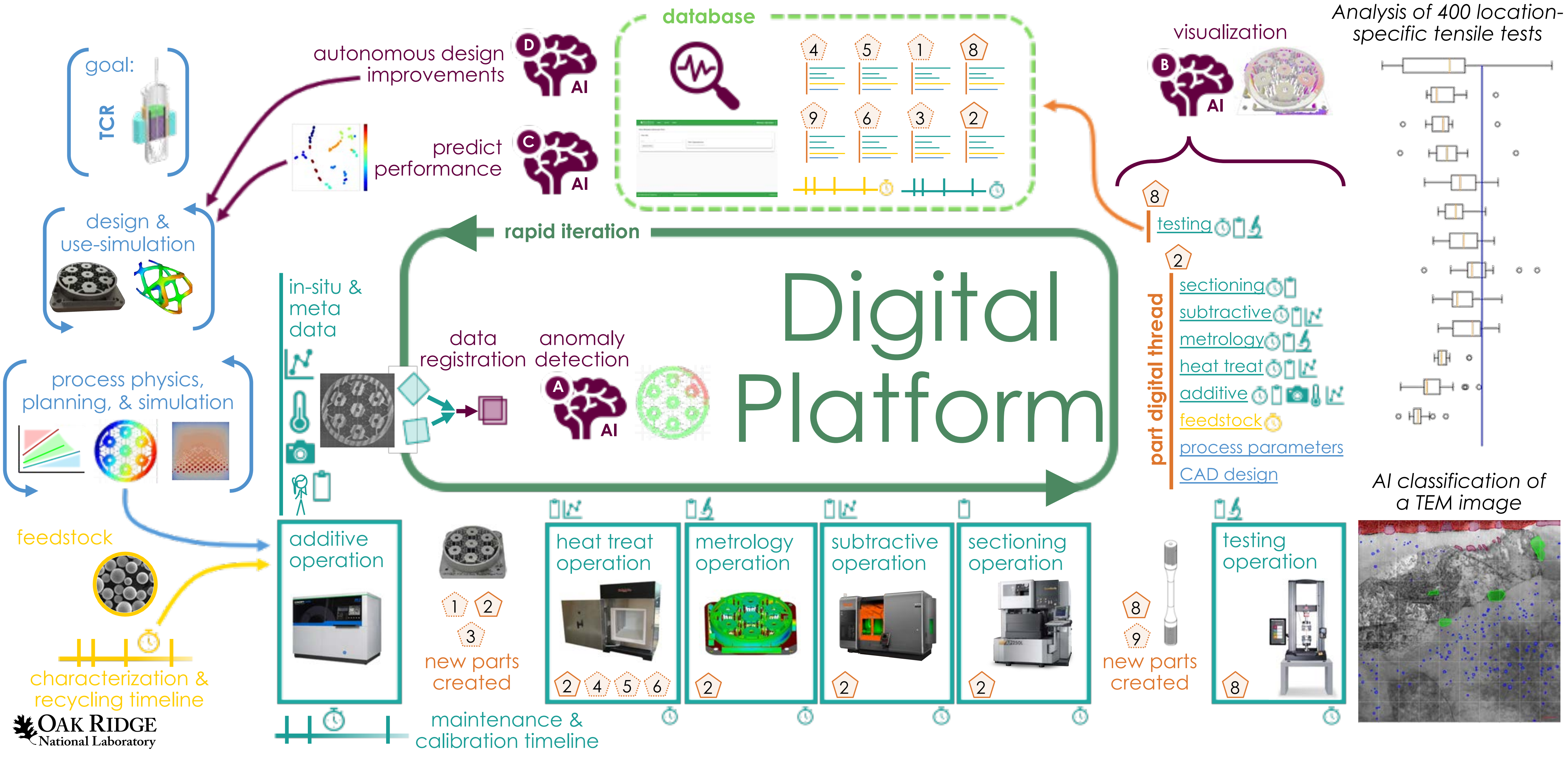
OAK RIDGE National Laboratory

Smart manufacturing approach supports new certification methodologies for these components





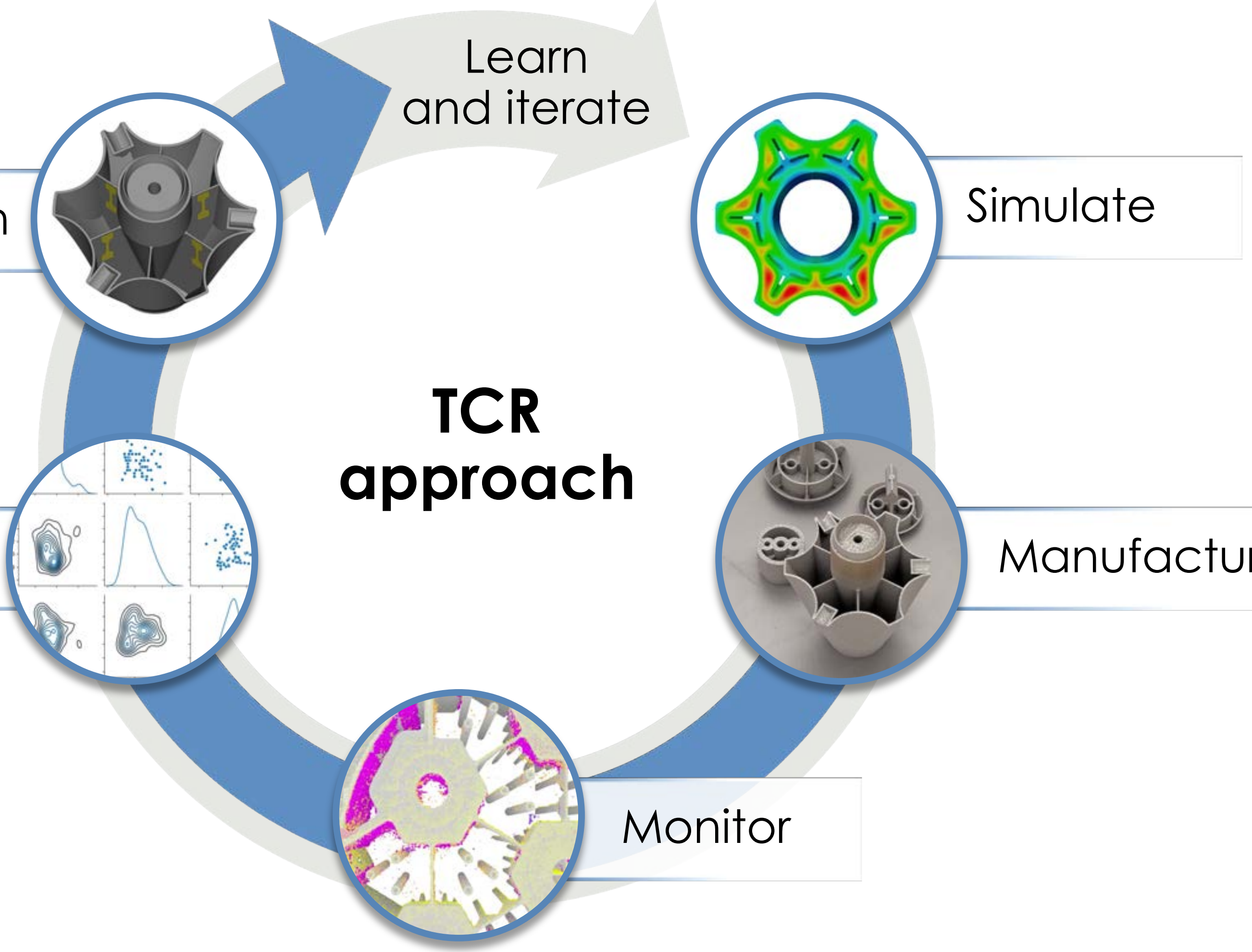
Using AI to assess critical component quality using in situ manufacturing signatures: Digital Platform for quality assurance



Oak Ridge National Laboratory

The agile design and development approach employed by TCR is intended to accelerate deployment

Agile approach breaks with traditional linear development models to exercise an iterative, dynamic development process



This approach lends itself to complex projects, in which a large, multilaboratory, multidisciplinary team works closely to complete a product

Potential applications for AM technologies to reprocessing facilities

- Reverse engineering of replacement or obsolete parts
- Embedded sensors for component health monitoring or additional measured data
- Design and fabrication of new components with more complex geometries

https://info.ornl.gov/sites/publications/Files/Pub118195.pdf

Concluding thoughts on additive manufacturing

- Continued development of additive manufacturing technologies will only widen their applicability in the nuclear reactor industry
- An economically viable application of additive manufacturing will likely involve a part redesign process
- Specific technologies rapidly progress, requiring periodic review of additive manufacturing methods and technologies

Source: TVA and Framatome

tcr.ornl.gov/publications

OAK RIDGE
National Laboratory